Upper Ocean Mixing

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LONG-TERM GOALS

To identify the major processes producing mixing in the upper ocean and to understand their dynamics sufficiently well to permit developing accurate parameterizations of mixing for use in numerical models.

OBJECTIVES

To understand mixing over continental shelves and slopes and in straits.

APPROACH

Our main technical work this year was developing SWIMS2, a depth-cycling towed body containing upward and downward 300 kHz ADCPs. Putting ADCPs close to the bottom is the only way to observe velocity and shear close to the bottom, owing to the masking of these signals by side lobe returns from shipboard ADCPs. Vern Miller did the mechanical design, Jack Miller designed electrical and digital circuits, and Earl Krause and Paul Aguilar constructed the vehicle. During March we tested SWIMS2 in Puget Sound, and during April and May we used it to study hydraulic responses to tidal flows in Puget Sound and the Hood Canal. It will next be used during the HOME Nearfield measurements in the Kauai Channel and Mamala Bay.

WORK COMPLETED

Fabrication and testing of SWIMS2 was completed, and it was prepared for use during the HOME Nearfield measurements.

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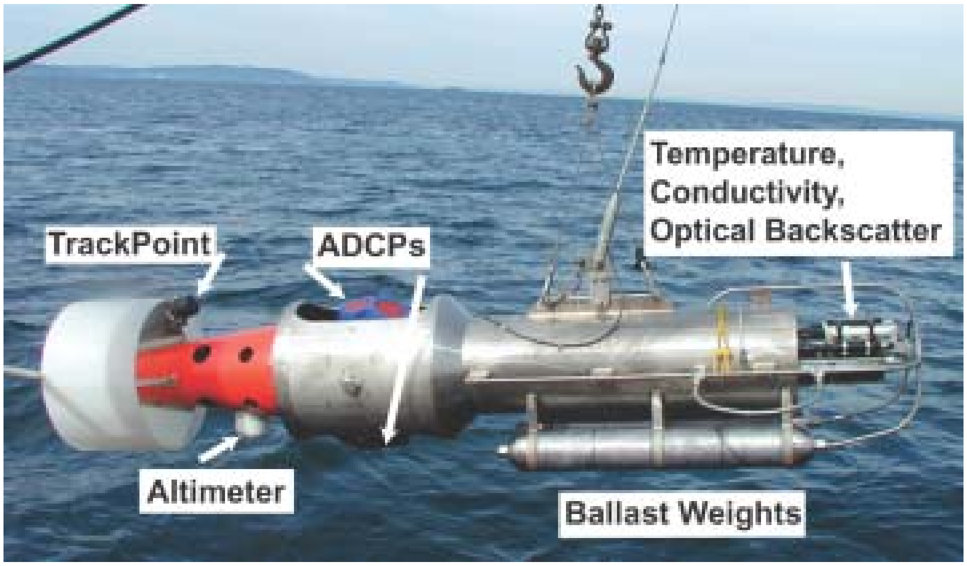

Figure 1. SWIMS2

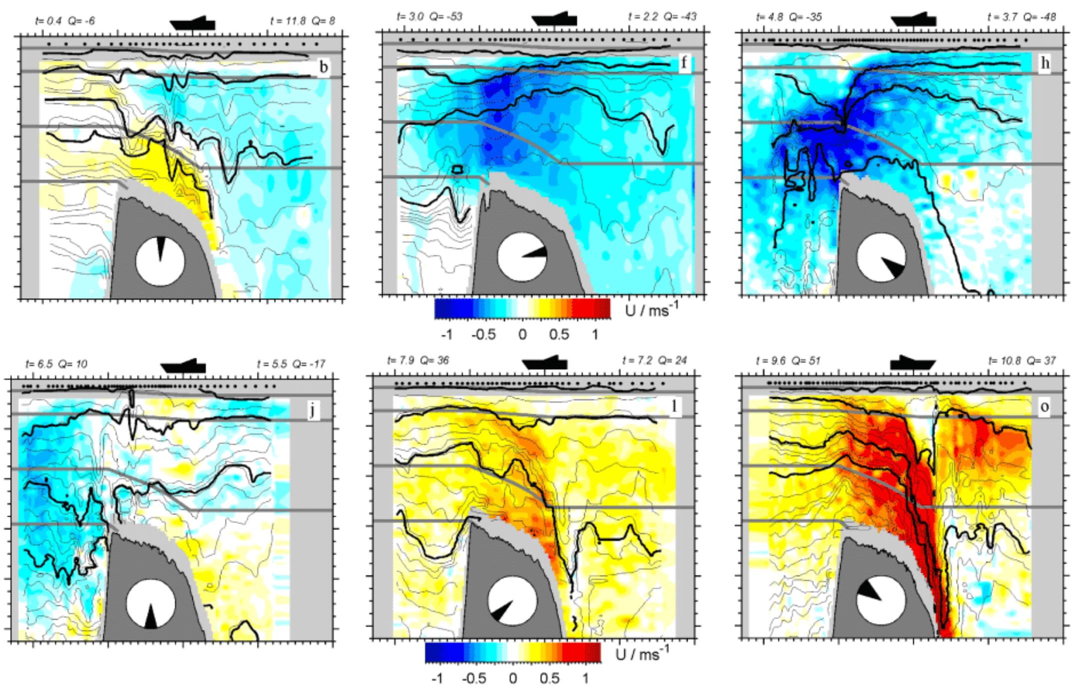

Fig. 2. Contrast between upstream response of tidal flow over the Knight Inlet Sill during ebb, top row, and during flood, bottom row (Klymak and Gregg, submitted). Insets on the sill show the tidal phase, with high water at noon, ebb at 3 o'clock, low water at 6 o'clock, and flood at 9 o'clock. Landward is to the right.

RESULTS

Klymak and Gregg (submitted) examined the large-scale response of tidal flows over the Knight Inlet sill and found that plunging flows are established much earlier during flood tides than during ebb tides (Fig. 2). Using model simulations they argue that this is mostly a consequence of the average contrast in density and stratification across the sill. This emphasizes the need to understand the large-scale response before focusing on details in a particular part of the flow.

Jennifer MacKinnon received her Ph.D. in June 2002 using observations we made on the New England shelf during CMO96 and CMO97. The former, taken when the water column was strongly stratified in late August, had diapycnal diffusivities of $K_\rho=(5-20)x10^{-6}\ m^2\ s^{-1}$, comparable to rates in the open ocean. Ms. MacKinnon analyzed both data sets to reveal the composition of the internal wave field and how its variability was linked to changes in mixing. Most of the kinetic energy was in the lowest 5 modes, as was the shear variance and shear^4 (Fig. 3). Energy and shear variances in each mode varied with little correlation between them. Also, the frequency spectra of the modes differed greatly, demonstrating that the spectra are not separable, as assumed in the Garrett and Munk model.

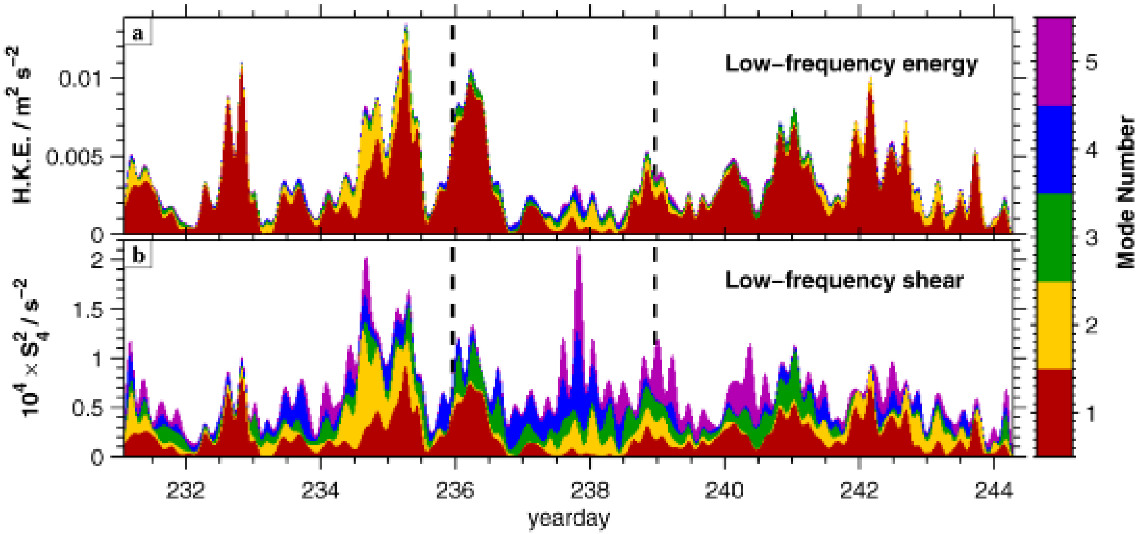

Fig. 3. Stacked histograms of a) horizontal kinetic energy in the first 5 baroclinic modes and b) Shear^4 for the same modes (MacKinnon and Gregg, 2002a). Note that changes in shear^4 are not proportionate to energy changes.

Solibores occurred throughout the observations but varied widely in amplitude and did not always appear. When they did appear, they rode the leading edge of the internal tide (Fig. 4) and were always mode 1. Strong shear across the zero-crossing produced overturns with intense pulses of turbulence that contributed about half of the mixing in the upper thermocline.

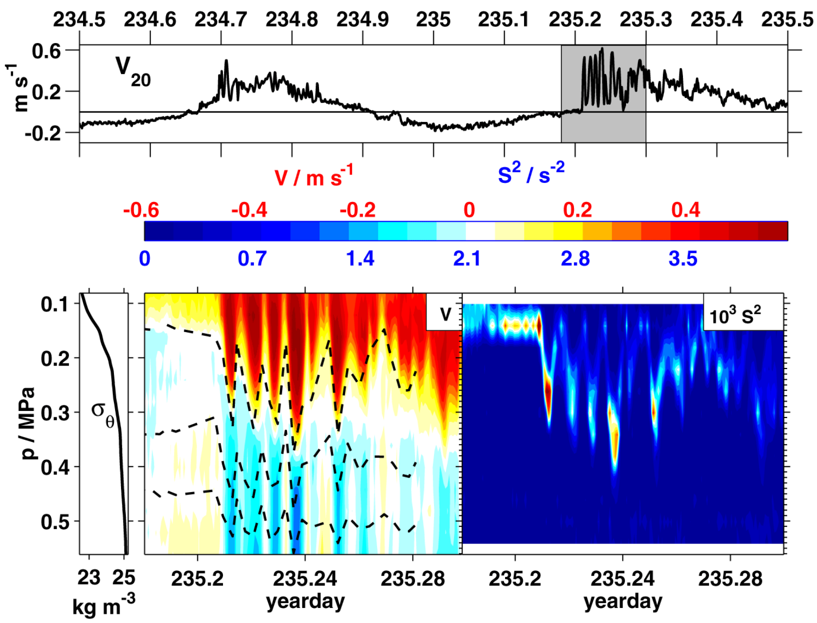

Fig. 4. Solibores in velocity and shear (MacKinnon and Gregg, 2002a). The upper panel shows northward baroclinic velocity at 20 m for one day. The lower panels show density, northward baroclinic velocity, and shear variance during the second solibore.

Panel a of Figure 5 shows the observed distribution of dissipation rates, ε, averaged over 4 meters versus 4-m shear variance and stratification. ε appears to increase nearly equally with both variables, unlike the Gregg-Henyey scaling which increases as shear^4 and N^2. This scaling, however, is based on a model of test waves with amplitude proportional to the background shear they are propagating through. Due to the uncorrelated nature of the modes on the shelf, this model clearly does not apply. Instead, Ms. MacKinnon represented the background shear by the low frequency shear, S_{lf}, and applied WKB scaling to the energy and vertical wavenumber of the test waves to obtain

$$\varepsilon = 3x10^{-11}\left(\frac{N}{N_0}\right)\left(\frac{S_{lf}}{S_0}\right) \quad \text{[W/kg]} \qquad (1)$$

where $N_0 = S_0 = 3$ cph, and the constant is an empirical factor required to match our observations. As seen in Figure 5, this model is much closer to the observations than the open ocean scaling.

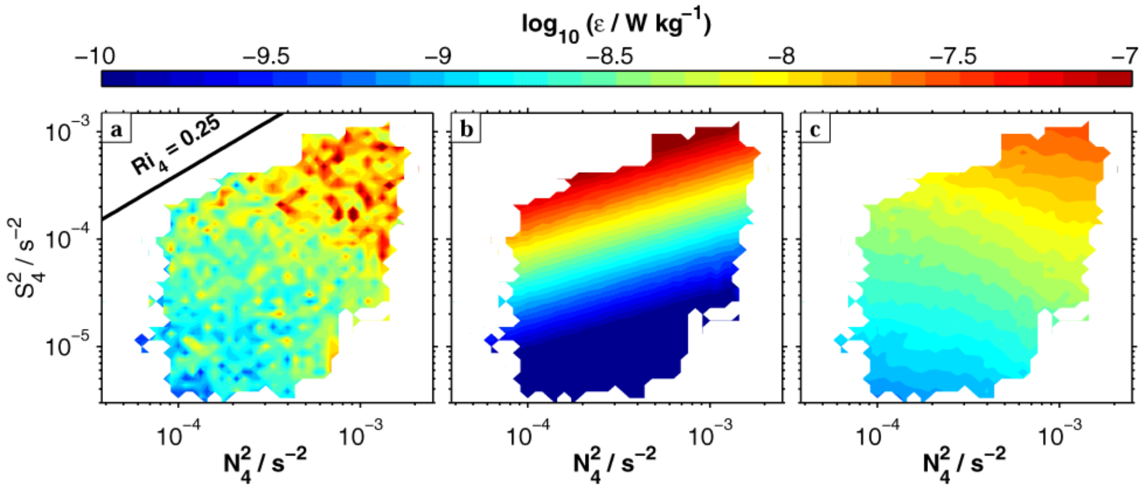

Fig. 5. Observed (a) and model (b,c) predictions of ε as functions of shear and stratification variances. Panel b shows the Gregg-Henyey model, and panel c the new MacKinnon-Gregg prediction.

Ms. MacKinnon will soon submit two more papers based on CMO97 when we observed the growth of stratification from the well-mixed conditions of winter. This scaling seems to work equally well with these data. Ms. MacKinnon will continue thinking about these issues as she develops modeling skills during a postdoc at Scripps with Kraig Winters.

IMPACT/APPLICATIONS

Demonstration of the large-scale time evolution of flow over the Knight Inlet sill should change the way hydraulically controlled flows are studied in the future. The MacKinnon-Gregg mixing model is the first we know of predicting mixing rates on shelves in terms of the local shear field and should be a target used by serious models of shelf circulation.

TRANSITIONS

Unknown.

RELATED PROJECTS

SWIMS1 was funded by Washington Sea Grant and used in Puget Sound and Knight Inlet for Sea Grant and ONR projects. Our Bosphorus work motivated Kraig Winters to develop modeling tools that deal realistically with channel bathymetry, including bends. This led to several papers with Andy Hogg and other work in progress.

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